Astrophysics with SNAP

ABSTRACT

While the primary science mission of SNAP involves thorough study of Type Ia supernovae and the nature of dark energy, the instruments have broad capabilities desirable for a wide variety of astrophysics. For example, the exquisite image quality and stable point spread function from space, and the wide field, is highly advantageous for weak gravitational lensing studies, allowing creation of a large scale map of the distribution of the dark matter in the universe. SNAP's repeated sky scanning opens up the time domain to investigations of rare, transient, variable, and moving objects while its magnitude depth and multicolor mapping enable studies of stellar and galactic populations, structure, and evolution. Deep photometry and high resolution in a microlensing survey would offer excellent opportunities for planet searches.

1. Design

The Supernova / Acceleration Probe (SNAP) is a mission concept for a 2 meter telescope in space with up to a one square degree field of view. Diffraction limited optics are achieved with a three mirror anastigmat. A near one billion pixel wide field imaging system is comprised of 144 large format new technology CCD's sharing a focal plane with 18-36 HgCdTe infrared detectors. Both the imager with 9 filters and a low resolution ($R \sim 100$) spectrograph cover the wavelength range 3500 - 17000 Å. In a single scan SNAP reaches magnitude $R = 28.8$, and is planned to achieve $m_{AB} = 31.6$ for coadded images. More details are given in the companion mission description document.

2. Science Reach

SNAP's capabilities can be summed up succinctly: wide, deep, and colorful. The main supernovae search covers a dozen square degrees while the planned weak lensing survey may encompass thousands of square degrees. The point source sensitivity limits in the 9 different bands as a function of area coverage range from $m_{AB} = 27 - 29$ as one goes from nearly full sky to 3000 square degrees. Copious cosmological and astrophysical information will be produced from the resulting wide, deep, multicolor images; in the main supernovae survey fields the dataset will cover a sky area almost 10000 times larger than the Hubble Deep Field and two magnitudes deeper.

Serendipitously, the baseline SNAP survey strategy is nearly ideal for a wide range of auxiliary science, e.g.

- Weak/strong gravitational lensing
- Microlensing and planet surveys
- Galactic structure and evolution
- Star formation, starbursts, multicolor mapping
- AGNs, variable stars, gamma ray burst afterglows
- Solar system studies

As one example, weak lensing science gains drastically reduced systematic uncertainties relative to ground observing, while retaining fairly large fields. With photometric redshifts weak lensing can play a key role in elucidating the origin and evolution of structure as a function of redshift. It also provides important complementary cosmological information crucial for dark energy investigations such as measuring Ω_m with uncertainties as low as $\pm$0.01-0.02, with little dependence on the dark energy equation of state w.

An exciting possibility is the opportunity to use SNAP's deep photometry and high resolution in a microlensing survey for planet searches. To sum up the advantages and promise of SNAP for Origins theme science:

- **Wider:** The wide field imager on SNAP is a natural scientific follow-on to the Hubble Deep Field; its baseline projects will provide the scientific community with data covering almost 10000 times the area of the HDF to approximately the same depth per exposure. SNAP also acts as a natural "feeder" – a survey telescope used to select targets for the NGST.
- **Deeper:** Typical scans go as deep as the HDF; deep fields reach coadded $m_{AB} = 31.6$.
- **More Colorful:** High accuracy multiband photometry in 9 filters covers the optical and near infrared from 0.35-1.7 μm.
- **More Often:** SNAP's scan strategy of a four day cadence in its primary fields opens up the time domain. Gamma ray burst afterglows, microlensing and strong lensing events, AGNs, variable and fast moving objects – the active, violent universe – will all be detected.

The combination of wide fields, deep exposures, and high resolution is not possible from the ground. The resulting data archives will be resources as invaluable as the Hubble Deep Field, used by scientists around the world and stimulating many areas of astrophysics. Moreover, the instrumentation is expected to become more and more available for Guest Survey programs as the primary missions ramp down over the first few years, giving wide access to the capabilities of this space observatory.

3. Community Synergy

The plethora of science generated covers myriad topics such as stellar populations, galactic structure, and clustering correlation functions, weak and strong gravitational lensing, evolution of large-scale structure, transient and rare objects, and solar system studies. In fact, just at the January 2002 American Astronomical Society meeting community researchers presented 18 talks and 6 posters in a special grouping dedicated to the broad range of science with SNAP (please see http://snap.lbl.gov/pubdocs/aastalks.html for the presentations).

In the attached document many of these speakers present their vision of exciting science that can be produced with the SNAP data archives and with the community Guest Survey opportunities. This early survey of science capabilities and goals ensures that the mission will be designed and implemented, as much as is possible consistent with the primary science, with the full potential of GO science in mind.

Science with Wide Field Imaging in Space
199th AAS Meeting
January 2002

Title	Author
The Astronomical Potential of Wide-field Imaging from Space	S. Beckwith (STSI)
Studying Active Galactic Nuclei with SNAP	P.S. Osmer (OSU), P.B. Hall (Princeton/Catolica)
Distant Galaxies with Wide- Field Imagers	K.M. Lanzetta (State University of New York at Stony Brook)
Angular Clustering and the Role of Photometric Redshifts	A. Conti, A. Connolly (University of Pittsburgh)
SNAP and Galactic Structure	I.N. Reid (STScI)
Star Formation and Starbust Galaxies in the Infrared	D. Calzetti (STScI)
Wide Field Imagers in Space and the Cluster Forbidden Zone	M.E. Donahue (STScI)
Galaxy Evolution: HST ACS Surveys and Beyond to SNAP (unable to present)	G. Illingworth (UCO/Lick, Univesity of California)
An Outer Solar System Survey Using SNAP (unable to present)	H.F. Levison, J.W. Parker (SwRI), B.G. Marsden (CfA)

Synopses of linked talks are appended

Wide Field Imaging in Space

Steve Beckwith

Recent discussions have identified areas for large initiatives that take advantage of the unique capabilities of space: low background, especially in the infrared, point spread function and photometric stability, full sky coverage and 24 hour operations. While the ground based telescopes retain their advantages of size – large aperture, and accessible focal planes fields of study like galaxy formation, AGN evolution, weak lensing, and supernova cosmology share an obvious synergy in the need for a ~1 square degree (and larger) HDF-like survey. And other programs, for example these:

- Earth-crossing asteroids (sensitivity.)
- Kuiper-belt objects (sensitivity., high resolution)
- Transient sources
- Supernovae (e.g. SN Ia) (sensitivity.)
- Micro-lensing sources (# stars)
- Dwarf stars: white, brown (sensitivity.)
- Quantify weak lensing in distant galaxies (high resolution, stable PSF)
- Parallaxes of faint stars (sensitivity.)
- Rare objects (survey to 27th mag)
- Eclipses of exo-planets
- Galaxy evolution

benefit tremendously from the unique space environment with its increased sensitivity to deeper limiting magnitudes as well as access to diffraction-limited optics. For example, detection of an extraterrestrial planet eclipse of duration ~ 3 hours requires precision photometry and high resolution.

Studying Active Galactic Nuclei with SNAP

Patrick S. Osmer (The Ohio State University)

Patrick B. Hall (P. Universidad Católica de Chile & Princeton University Observatory)

- The proposed SuperNova/Acceleration Probe (SNAP) offers the chance to study thousands of active galactic nuclei (AGN) just in its primary imaging of 20 square degrees of sky to a coadded AB=32.

- Time sampling of every two days or better for 1.5 years will yield the largest sample to date of variability-selected AGN. A multicolor selected sample can also be created through use of SNAP's several filters and aperture photometry of only the nuclear regions of galaxies.

- The very complete AGN sample in the primary SNAP imaging area would consist of ∼5000 quasars and ∼100,000 AGN to M_B=−16. This sample will enable studies of variability as a function of luminosity and many other parameters at $z \lesssim 2$. It will also map the redshift evolution of the L_{nuc}-L_{bulge} relation to $z \sim 2$.

- Time sampling of so many AGN (and other galaxies with supermassive black holes) enables detection of strong flares; e.g., ∼20 flares from the tidal disruption of a star by a supermassive BH.

Science with the SNAP AGN samples

- Photometric redshifts for 10^5 AGN host galaxies: study colors, morphologies, spatial clustering, and correlations of same with L, z.

- Number density & luminosity function (LF) evolution of AGN to $M_B \sim -16$. Sarajedini et al. [ApJ 514, 746] find evidence for mild number density evolution of AGN to $z \sim 1$ at such M_B. The observed evolution appears to be neither pure luminosity evolution, nor pure density evolution. SNAP could characterize this evolution.

- Redshift evolution of the fraction (and B/D ratios) of galaxies hosting AGN ($\sim$1-3% BLAGN & $\sim$10-30% NLAGN at z<1).

- Redshift evolution of the L_{nuc}-L_{host} relation: Rix et al. [astro-ph/9910190] show that 5 of 6 AGN at $z \sim 2$ have less luminous (less massive) hosts than similarly luminous AGN at $z \sim 0.2$.

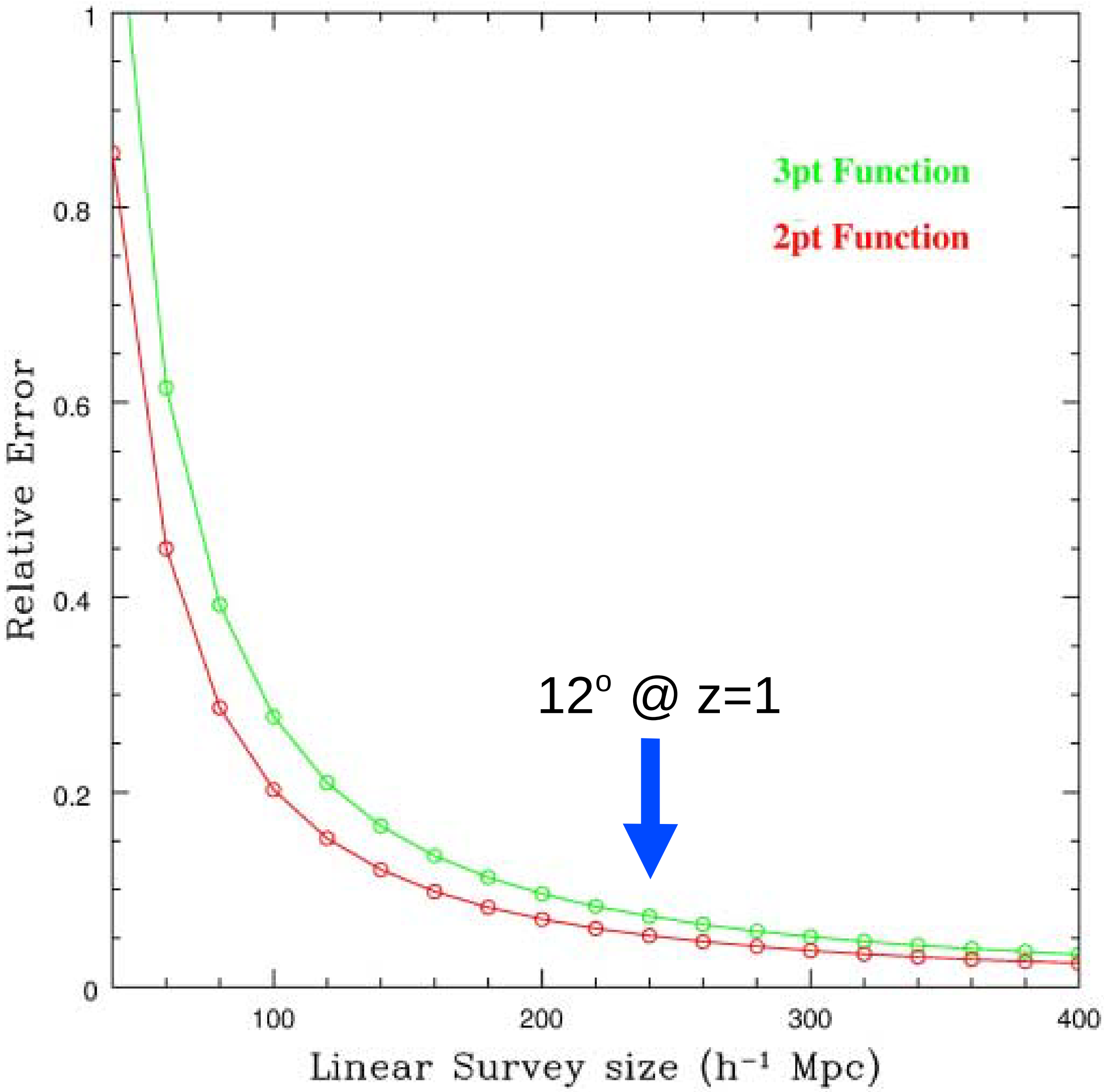
- L_{nuc}-L_{bulge} relation difficult to study, since bulges & nuclei are somewhat degenerate at this resolution [Sarajedini et al. ApJ 514, 746]. High SNR of coadded SNAP data will help, as will the fact that minimum detectable L_{nuc} is lower for less luminous galaxies.

- Dependence of AGN variability on M_B & redshift, even host galaxy type (since LINER:Sy2:Sy1 abundance is a function of galaxy type).

- Simultaneous X-ray monitoring for X-ray-UV-optical variability? Contemporaneous ground based spectrophotometry for reverberation mapping of quasar BELRs?? (Lag time $\sim$100 days at $B\sim$21)

Angular Clustering and the Role of Photometric Redshifts

A.Conti and A.Connolly



A sky survey of the dimension of the main SNAP fields could estimate the angular correlation function of galaxies at z ~1 to 5% while the planned wider, shallower survey could determine it at the ~3% level.

Deep Wide-Field Space-based Imaging and Galactic Structure

Neill Reid (STScI)

Wide-field surveys (POSS I&II, 2MASS, SDSS, SNAP,etc.) don't just image galaxies.

Starcount analyses probe the structure of our Galaxy
⇒ provide insight to galaxy formation

SNAP permits detailed study of the Galactic halo*, *in situ* at $Z > 5$ kpc.
⇒ first major epoch of star formation
Still the only halo where such detailed observations are possible.
*Galactic halo ≡ old,metal-poor *stellar* population

Why is deep imaging necessary?

Starcount analysis relies on photometric distance estimators

Ground-based surveys probe magnitudes brighter than $V \sim 21$ to 22
⇒ $M_v < +5$ in the halo

- Red giants – steep CMD, poor distance estimator
- Subgiants – abundance sensitivity, poor distance estimator
- Turnoff stars – steep CMD, poor distance estimator
- HB stars – abundance sensitivity, moderate distance estimator

Need to go deeper to reach unevolved subdwarf main sequence.

Why space-based imaging?

Galactic structure analysis requires high accuracy star/galaxy separation techniques

- Analysis of groundbased observations is limited by seeing
- Require large fields of view – so AO is little help
- Galaxies basically look like K stars – can't separate by colour
- High accuracy proper motions provide additional discrimination

Space-based observation are essential at $R >$ 22nd magnitude.

Science issues summary:

1. Halo density law – from counts at faint magnitudes

- Is there an edge to the halo?
- Spatial sub-clustering – how well-mixed is the halo?
- Vertical density distribution for very late-type disk dwarfs.
- Only ~10 halo stars seen in HDF; SNAP's wide area and depth really helps for statistical analysis.

2. Proper motions for faint halo stars

$\rightarrow$ kinematics in thick disk/halo at $Z > 5$ kpc, i.e. disk/halo transition region.

3. Probe halo luminosity function at faint absolute magnitudes *in situ*

4. Repeat observations should allow identification of faint variable stars (statistics on flares in low-mass halo subdwarfs?), contact binaries and, in particular, eclipsing binary systems
$\Rightarrow$ potential mass measurements (if the candidates are accessible to spectroscopy).

Limitations:

1. Limited coverage in $(l, b) \Rightarrow$ limited sensitivity to certain structural parameters.

2. Star/galaxy separation requires well understood psf as f(position).

3. Even relative astrometry requires stable psf as f(position).

Deep starcount studies demand stable, reliable, well-calibrated images
$\rightarrow$ *but so does the supernova project. . .*

Star Formation and Starburst Galaxies in the Infrared

Daniela Calzetti (STScI)

The unanswered questions in star formation are: What are the regulating mechanisms? What determines the intensity, duration and triggers of a star formation event? How are these mechanisms tied to the global properties of the host galaxies? How many modes of star formation are there?

Since regions of star formation are most heavily obscured by dust, multi-wavelength data provides the advantage in discriminating between the effects of dust and the effects of age on stellar populations, see figure 1 below. For example, U-B is an age indicator.

High spatial resolution in the optical and the infrared, combined with the advantage of photometric stability in space provides images of resolved, individual stellar components (clusters) in nearby galaxies. A telescope like SNAP, reaches m(AB) = 29 mag with S/N = 5 in 10,000 seconds, allows the detection of a 10^4 M_o, 10 Myr old cluster at a distance of 12.5 Mpc and of a 10^4 M_o, 100 Myr old cluster at a distance of 5 Mpc. A wide field of view, of order a degree, enables detailed study of local galaxies which have angular diameters of a few arcminutes to 40 arcminutes.

Studying the age distribution and star formation histories of young stellar populations in nearby galaxies will provide clues on the regulating mechanisms. To get effective age determinations, for both resolved and unresolved stellar populations, requires homogenous sets of multi-wavelength data, such as those SNAP can provide.

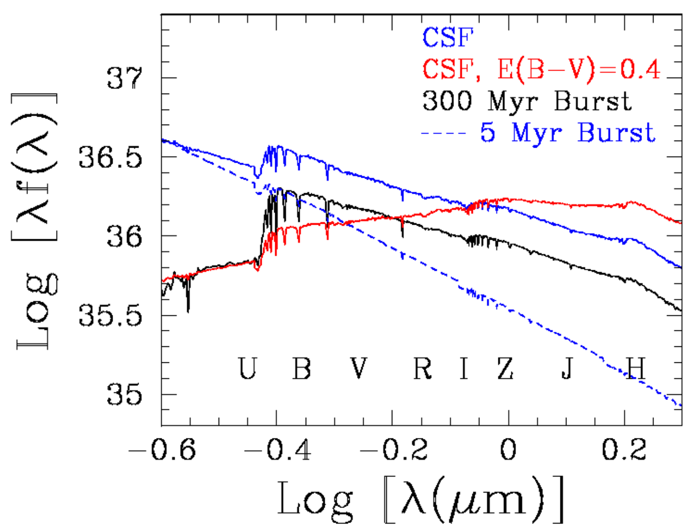


Figure 1: Plotted are the spectral energy distributions of continuing star formation with (red) and without (solid blue) dust obscuration, and of a single star formation burst 300 Myr old(black) and 5 Myr old (dashed blue).

Cluster Discovery in the Forbidden Zone

Megan Donahue (STScI)

The main points:

Clusters are interesting because they are the most massive virialized systems in the universe. As such, they are thought to be fair samples of, for example, the ratio of baryons to dark matter. The number of clusters as a function of redshift directly reflects the growth of structure, as driven by gravitational processes alone, with the initial conditions of the original density perturations. The current model of structure formation predicts that the evolution of clusters will be much faster in the epoch $z > 1.5$. However, to date, this epoch of cluster evolution has been very difficult if not impossible to probe. Because of the k-correction effects of old galaxy population, the sensitivity of optical surveys drop like a rock at $z > 1 - 1.4$. X-ray surveys lose their sensitivity as the surface brightness of the highest redshift sources fade below the particle backgrounds of the detectors. Lensing surveys require significant numbers of background sources. Sunyaev-Zel'dovich surveys hold promise, because the detection of the S-Z effect against the cosmic microwave background is independent of the cluster redshift, as long as a high pressure intracluster medium is present. Space-based, wide-angle infrared imaging provides arguably the best opportunity to locate and study high redshift ($z = 1.5 - 2.5$) clusters of galaxies, for a moderate sized telescope (2 meter class) and a wide field of view (sq degree). Lifting the telescope above the atmosphere strikingly reduces the sky background and allows pristine clarity over a large field of view.

GO program 1:

A 1000 square degree high-galactic latitude survey of random fields, not necessarily contiguous, with exposure depths of $\sim$1000 seconds of such an instrument would allow for the discovery of high redshift clusters of galaxies, independent of the presence of a radio source or a hot and dense intracluster medium. Such a survey could also provide redshift estimates of all cluster candidates via photometric redshifts. See Evrard et al. (in the AAS talk, or on astro-ph/0110246)

OR

GO program 2:

A pointed GO program could also be constructed to followup on S-Z candidates and provide confirmation and necessary photometric redshifts. Such a program is contingent on the maturity of the S-Z observations at the time of SNAP.

Note: If PRIME is selected from Phase A (they will know July 2002), this cluster science will be done over a larger region of sky (up to 10,000 degrees), and S-Z teams may take their searches to coordinate with PRIME. If PRIME does not get selected, the SNAP cluster GO program takes on a much higher priority, because the science will not be accomplished from the ground.